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(54) **Bipolar filtered feedthrough terminal.**

(57) A bipolar feedthrough terminal (10) provides an electrical connection between two different environments, such as between the electrical circuits within a hermetically sealed pacemaker case and the connector block assembly to which two pacemaker leads (18, 20) are ultimately attached. Included as an integral part of the feedthrough terminal is a capacitor disk (30) made up of several laminations which provide two separate parallel plate capacitors from either lead to ground. Capacitive filtering thus protects the pacemaker circuits from electromagnetic interference.

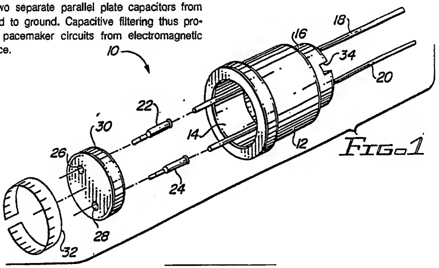

FIG. 1

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BIPOLAR FILTERED FEEDTHROUGH TERMINAL

The invention relates generally to hermetically sealed feedthrough elements, and in particular to such an element utilizing a dual capacitor circuit for electromagnetic interference (EMI) protection for cardiac pacemakers.

BACKGROUND OF THE INVENTION

The technology of cardiac pacemakers has reached a state of highly sophisticated system performance. The present generation of cardiac pacemakers uses microprocessors and related circuitry to sense and stimulate heart activity under a variety of physiological conditions. Currently available pacemakers can be programmed to control heart function in correcting or compensating for various cardiac abnormalities which may be encountered in individual patients. An extensive description of modern cardiac pacemaker technology is given in International Application No. PCT/US85/02010, entitled "Stimulated Heart Interval Measurement, Adaptive Pacer and Method of Operation," assigned to the assignee of the present invention. The disclosure of that application is incorporated herein by reference.

In brief, a cardiac pacemaker consists of a generator unit surgically implanted in the chest of a patient and connected to leads implanted in the heart. The heart leads are used both for sensing the electrical activity of the heart and for providing electrical stimuli to control the functioning of the heart. Connection of the heart leads to the pacemaker generator unit is made through hermetically sealed feedthrough terminals in the cap of the pacemaker.

It is desirable to eliminate electromagnetic interference from being fed into the leads entering the generator unit of a pacemaker. This can be done by using capacitive filtering. Previously, capacitive filtering for EMI protection was effected through utilization of discrete capacitors wired into the circuitry. The impedance of the leads going to the discrete components prevented the broad spectrum filtering that is ideally desired. Furthermore, some types of hermetic feedthrough elements involving capacitors for filtering can only be tested after final assembly, and if one part fails the test, the remainder of the assembly cannot be reworked or salvaged, thereby incurring substantial waste. It would be a significant advance in the technology of hermetically sealed feedthrough elements if one could be designed in such a way as to provide broad spectrum filtering of EMI and at the same time provide an economical and efficient unit for which testing of all component parts could be completed before committing to final assembly.

SUMMARY OF THE INVENTION

In brief, arrangements in accordance with the present invention utilize a hermetically sealed feedthrough element with a dual capacitor circuit for electromagnetic interference protection for cardiac pacemakers. Novel capacitor and feedthrough structure results in broad-spectrum filtering and convenience in testing.

The purpose of the feedthrough element is to carry two circuit conductors from inside the pacemaker housing to connect to terminals into which the pacemaker leads are inserted. The feedthrough element of the invention is formed of a titanium body with a ceramic plug mounted at one end. The ceramic plug or end cap has the two conductors mounted in it, and is mounted in the titanium body to project slightly from one end, thereby providing a longer path length between the conductors and the titanium housing, which is ground, or reference potential. The end of the ceramic plug is also provided with a transverse slot located between the two conductors on the exterior side of the plug so as to provide a longer leakage path between the conductors. The ceramic end cap is sealed to one end of the titanium body with Kyroflex™. Into the other end of the titanium body is fitted an EMI capacitor in the form of a laminated disk comprising individual layers coated with thick conductive film to provide two sets of interleaved capacitive plates. One set consists of disk layers having openings about the two conductors and arranged to make contact with the outer circumferential surface of the end cap. The other set is circular with a circular film coating having a diameter less than the diameter of the end cap, with holes for two contact tubes which accommodate the conductor leads. This set of disk layers has alternate electrical connection of the conductive film layers with one or the other of the contact tubes. Two separate parallel-plate capacitors are thus formed which link the terminal leads with the titanium body ground.

Another important aspect of the invention is the way in which electrical connection is made between the outer circumference of the EMI capacitor, which is plated, and the inner diameter of the titanium body. Connection is made with a contact ring that starts out as a flat strip which is stamped along one edge by shear forming to develop a

series of slightly rotated segments that project in alternate directions at both edges from the plane of the strip. The strip is then formed into a circle with a gap between the two ends. This contact ring is held around the capacitor disk and both are inserted into the titanium housing. The sharp edges of the rotated tabs on the contact ring make the desired contact between the inner surface of the titanium shell and the outer surface of the capacitor disk. The circuit connection is firmly established both mechanically and electrically. One advantage of this type of construction is that the capacitor disk can be tested as a unit before it is installed in the titanium body. After installation, the outer surface of the titanium body is resistance welded to the pacemaker housing and the outer ends of the two connecting tubes are welded to the corresponding conducting leads. The EMI protection provided covers an effective range from 27 MHz to 2.45 GHz.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objects, features and advantages of the present invention will be more apparent from the following more particular description thereof presented in conjunction with the accompanying drawings, wherein:

FIG. 1 is an exploded view of the bipolar filtered feedthrough terminal of the present invention;

FIG. 2A is an end view of the ceramic end cap of the terminal of FIG. 1 as seen from the outside of the feedthrough terminal;

FIG. 2B is a side view, partially broken away, of the end cap;

FIG. 3A is an end view of one contact tube of FIG. 1;

FIG. 3B is a partially broken away side view of the contact tube;

FIG. 3C is a sectional view along the line A-A in FIG. 3B after the vertical diameter has been slightly deformed;

FIGS. 4A-4C are plan views of three types of laminations of the EMI capacitor;

FIG. 5A is a schematic diagram of the two interleaved parallel-plate capacitors;

FIG. 5B is a schematic electrical diagram of the two separate capacitors formed by the laminations of the EMI capacitor;

FIG. 6A is a plan view of the sheer-formed metal strip from which the contact ring is made;

FIG. 6B is an elevational view of the sheer-formed metal strip of FIG. 6A;

FIG. 6C is a detailed view of the area marked A in FIG. 6B; and

FIG. 6D is a top view of the contact ring made from the sheer-formed metal strip shown in FIGS. 6A-6C.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

A bipolar filtered feedthrough terminal in accordance with the present invention is shown in the exploded view of FIG. 1. The feedthrough terminal 10 houses several components in a cylindrically symmetrical metal shell 12 having a central cylindrical bore 14 on its longitudinal axis. A ceramic end cap 16 is hermetically sealed into one end of the shell 12 with leads 18 and 20 extending through end cap 16 into the interior of shell 12. Leads 18 and 20 are hermetically sealed in holes through ceramic cap 16. Contact tubes 22 and 24 fitting onto the interior ends of leads 18 and 20 in turn fit through holes 26 and 28 of the EMI capacitor 30. EMI capacitor 30 comprises a series of laminations which consist of patterns of thick conducting films laid down on insulating substrates to form separate capacitors between contact tubes 22 and 24 and shell 12, which is maintained at a selected reference potential; e.g., ground. The different types of laminations and their order in forming EMI capacitor 30 are explained in detail below. A metal contact ring 32 fits around the outer circumference of EMI capacitor 30, which is metal plated, and inside the inner circumference of hole 14 in shell 12 to establish the common connection.

Shell 12 is preferably made of titanium metal. Ceramic end cap 16 is bonded into one end of the shell 12 with a material such as Kyroflex™, which is fired at about 1400°F. As shown in FIG. 1, ceramic end cap 16 is inserted only part way into shell 12, with roughly half of its thickness inside shell 12 and the other half outside shell 12. This partial insertion has the effect of increasing the resistive path length over the surface of the ceramic between leads 18 and 20 or between either lead and the shell 12, which is ground. The leakage resistance path between leads 18 and 20 is further increased by slot 34 in the exterior face of end cap 16.

Ceramic end cap 16 is shown in more detail in FIGS. 2A and 2B. End cap 16 is made from an insulating ceramic such as alumina. Parallel feedthrough holes 36 and 38 to either side of slot 34 allow passage of leads 28 and 20 from the outside of end cap 16 to the interior shell 12. Leads 18 and 20 are hermetically sealed to end cap 16 with Kyroflex™

FIGS. 3A and 3B show end and side views,

respectively, of one of the contact tubes 22, 24. Contact tubes 22 and 24 are preferably made from seamless nickel 200 tube, with No. 1 annealed temper, having an outer diameter of 0.020 inch maximum and inner diameter 0.014 inch minimum. Contact tube 22 comprises an end portion 22a, a flange 22b, and an intervening body portion 22c. Body portion 22c has a larger diameter than end portion 22a. As shown in FIG. 3C, which is a sectional view across the line indicated in FIG. 3B, wherein body portion 22c is squeezed so that it assumes an elliptical cross section. The outer diameter of contact tube 22 is nominally 0.0225 inch to begin with, and is deformed out of round by about .004 inches. The end portions 22A and 24A of contact tubes 22 and 24 are inserted through corresponding holes 26 and 28 in EMI capacitor 30 until the ferrules 22B and 24B at the ends of the body portions 22C and 24C bottom on the cap. The body portions 22C and 24C of contact tubes 22 and 24 are designed to provide interference fits in holes 26 and 28 of EMI capacitor 30.

EMI capacitor 30 is a laminated disk which is punched out of a lamination made from individual insulating layers coated with thick conductive film to provide interleaved capacitive plates with differing shapes of film on successive layers. In FIGS. 4A-4C, the different types of laminations are shown. The first type of lamination, 39, has a layer of conducting film 40 entirely covering the substrate except for small circular islands 41 and 42 surrounding holes 26 and 28. The second type of lamination, 43, has a circular area 44 of conducting film which is slightly smaller in diameter than the underlying substrate 45, with a small uncovered island 46 surrounding hole 28. The third type of lamination, 47, is in reality the same as 43 but rotated through 180° in the plane of the disk. Lamination type 47 has its small uncovered island 50 surrounding hole 26, so that when contact tubes 22 and 24 are inserted through holes 26 and 28 in the lamination, circular area 52 of conducting film makes contact with tube 28 but not with tube 26. The opposite is true for lamination type 43. Insertion of contact tubes 22 and 24 through a lamination type 39 results in no electrical contact between the conductive film 40 and either tube.

FIG. 5A is a schematic electrical diagram of a bipolar capacitor disk 30 made up of nine laminations. Laminations 39a, 43a, 39b, 43b, and 39c form a parallel-plate capacitor 54 (FIG. 5B) between contact tube 22 and shell 12 (ground). A separate parallel-plate capacitor 56 is formed between contact tube 24 and shell 12 (ground) by laminations 39c, 47a, 39d, 47d, and 39e. The outer circumference of bipolar capacitor disk 30 is metal plated to provide electrical contact between all laminations of type 39 in the lamination stack. Contact between the plated outer periphery of bipolar capacitor disk 30 and the inner circumference of shell 12 is made through contact ring 32, which is shown in detail in FIGS. 6A-6D.

Contact ring 32 starts out as flat strip of metal 54 as shown in FIG. 6A. Metal strip 54 is stamped along one edge by sheer forming to develop a series of slightly rotated segments 56 that project in alternate directions at both edges from the plane of the strip 54. The slightly rotated tab-like segments 56 are shown in the elevation view of FIG. 6B, and in further detail in FIG. 6C. Strip 54 is then formed into a circular ring with a gap between the two ends, as shown in the top view of FIG. 6D. Contact ring 32 is placed around capacitor disk 30 and then both are inserted into the titanium housing 12. The tab-like segments 56 project in the outward direction away from shell 12 as contact ring 32 and capacitor disk 30 are being inserted together. The sharp edges 56A and 56B of the rotated segments 56 make the desired contact between the inner surface of shell 12 and the outer surface of capacitor disk 30, thus firmly establishing the integrity of the circuit connection.

One of the advantages of this type of construction is that the capacitor disk 30 can be tested as a unit before it is installed in the shell 12. After installation, the outer surface of the titanium body of shell 12 is resistance welded to the pacemaker housing. The outer ends of contact tubes 22 and 24 are also resistance welded to the corresponding conducting leads 18 and 20.

Although the capacitor disk 30 is represented in FIG. 5A as comprising nine separate laminations or conducting layers interleaved together, that is merely by way of example and other, equivalent configurations may be utilized as, for example, a different number of laminations having different areas making up the individual conducting layers. A preferred minimum value for the capacitance of the disk 30 is 2700 pf., but this may be increased as desired over a range up to 100%. The measurement of capacitance in determining the value is made at 1 KHz and 1.0 volts rms.

The capacitor disk 30 is manufactured and sold by U.S. Microtek Components, having an address of 11144 Penrose, Sun Valley, California. The dielectric characteristics of the capacitive disk 30 are in accordance with code X7R, a standard designation well-known to those skilled in the related art.

In one preferred embodiment of the invention, the disk 30 was nominally .050 inches thick with a nominal outside diameter of .114 inches. The holes 26, 28 were each .0230 inches in diameter, spaced .275 inches on opposite sides from the center of the disk 30 along a diameter thereof. The strip 54 from which the ring 32 is fabricated is nominally .050 inches wide by .370 inches long, cut from

.003-inch stock. The edge portion of the strip 54 which is shear-formed to develop the tabs 56 is approximately .015 inches wide, and each tab 56 is twisted sufficiently to project approximately .002 inches from the planar surface of the strip 54.

Protection from EMI is provided over a spectrum extending from about 27 MHz to 2.45 GHz. The impedance of the leads which are present in conventional capacitive filtering devices using discrete capacitors is eliminated. Testing of the present feedthrough element 10 is more convenient because the capacitor disk 30 can be tested as a unit before it is installed in shell 12. Therefore, there is no loss of titanium shell components as there would be if the feedthrough element were found to fail after assembly, as is done in conventional filtering systems.

Although there has been described above one specific arrangement of a bipolar filtered feedthrough terminal for a pacemaker in accordance with the invention for the purpose of illustrating the manner in which the invention may be used to advantage, it will be appreciated that the invention is not limited thereto. Accordingly, any and all modifications, variations or equivalent arrangements which may occur to those skilled in the art should be considered to be within the scope of the invention as defined in the annexed claims.

Reference list

10 feedthrough terminal
12 shell
14 bore
16 end cap
18,20 leads
22,24 contact tubes
22a,24a end portion
22b flange
22c body portion
26,28 holes
30 capacitor
32 contact ring
34 slot
36, 38 holes
39,39a,b,c,d,e lamination
40 conducting film
41,42 circular islands
43, 43a,b lamination
44 circular area
45 underlying substrate
46 uncovered island
47, 47a,d lamination
50 uncovered island
52 circular area
54,46 capacitor/strip/segments/tab

Claims

1. A bipolar filtered feedthrough terminal comprising:
a cylindrical conductive tubular shell;
an insulating end cap having first and second electrical leads extending therethrough and hermetically sealed therein, said end cap being hermetically sealed inside a first end of said shell;
first and second metallic contact tubes mounted on ends of said leads inside said shell; and
a laminated bipolar capacitor disk fitting into a second end of said shell with said first and second contact tubes passing through said disk, said disk providing separate capacitors between said shell and respective first and said second contact tubes.

2. The terminal of claim 1 further including resilient conductive means fitted between an outer periphery of said laminated disk and an inner surface of said shell for providing electrical connection between said capacitors and said shell.

3. The feedthrough terminal of claim 1 wherein said bipolar capacitor disk has a plated outer circumference and comprises a plurality of laminations, each said lamination comprising a thick conductive film on an insulating substrate and having first and second tube holes therethrough, there being at least two discrete types of laminations classified according to the shape of the conductive film thereon, with no two adjacent laminations being of the same type.

4. The terminal of claim 3 wherein a first lamination type comprises thick conductive film extending to the peripheral edge of the lamination but spaced from said tube holes, and a second lamination type comprises thick conductive film extending to the edge of only one of said tube holes and spaced from the peripheral edge of the lamination.

5. The terminal of claim 4 wherein a pair of laminations of said second type are arrayed on opposite sides of a lamination of said first type with said pair being oriented to make electrical contact with respective ones of said first and second contact tubes, thereby forming separate capacitors between said respective first and second contact tubes and said lamination of said first type.

6. The terminal of claim 4 wherein said laminations are arrayed to form interleaved parallel-plate capacitors, one such capacitor between said first contact tube and said shell, and a second such capacitor between said second contact tube and said shell.

7. The terminal of claim 4 wherein said bipolar capacitor disk comprises n laminations of the second type and n+1 laminations of the first type interleaved together with n/2 laminations of the second type connected together to the first contact tube and the remaining laminations of the second

type being connected together to the second contact tube, the laminations of the first type being connected together to a common reference point.

8. The terminal of claim 2 wherein said resilient conductive means comprises an unclosed ring of a thin metallic strip with a plurality of tabs having edges protruding from the ring surfaces to establish contact between the peripheral metallic surface of the disk and the inner surface of the shell.

9. The terminal of claim 8 wherein said tabs are formed by a plurality of transverse cuts in the thin metallic strip along one edge thereof, each tab being twisted slightly with respect to an adjacent uncut portion of said strip contiguous with said tab.

10. A bipolar filtered feedthrough terminal for providing electrical connection from a first, hermetically sealed environment to a second environment, comprising:
a cylindrically symmetrical conducting shell having a cylindrical bore therein extending along a longitudinal axis;
a ceramic end cap hermetically sealed into one end of said cylindrical bore, said cap having first and second electrical leads extending generally parallel to said axis through said ceramic end cap and hermetically sealed therein;
first and second metallic contact tubes having inner diameters fitting said first and second electrical leads and mounted thereon within said bore; and
a laminated bipolar capacitive cylindrical plug with first and second holes therethrough for said first and second contact tubes, each lamination of said plug consisting of a thick conducting film on an insulating substrate, with films connected to said shell and to said first and second contact tubes so as to form separate first and second parallel-plate capacitors between said first contact tube and said shell and between said second contact tube and said shell, respectively.

11. The terminal of claim 10 wherein the outer circumference of said plug is plated with a conductive metal layer and further including a contact ring fitting between said outer circumference of said laminated plug and an inner surface of said shell to establish electrical connection therebetween.

12. The terminal of claim 11 wherein said contact ring comprises a strip of thin metal having a plurality of parallel cuts therein along one long edge thereof to form a plurality of rectangular tabs, each tab being twisted slightly to provide edges for contacting the metal surface of the plug and the inner surface of the shell, said strip being formed into an unclosed ring.

13. The terminal of claim 12 wherein said contact ring comprises nickel having a thickness of about 0.003 inch, and each tab is substantially square with a length equal to roughly 0.3 times the width of said strip.

14. The terminal of claim 10 wherein each contact tube comprises an end portion at a first end of said tube having a first diameter, a flange at a second end of said tube, and a body portion between said end portion and said flange, said body portion having a second diameter which is greater than said first diameter and less than the diameters of said first and second holes to permit insertion therein.

15. The terminal of claim 14 wherein said body portion is deformed out of round to establish an interference fit when inserted into a corresponding hole in said plug.

16. The terminal of claim 10 wherein said ceramic cap defines a transverse slot in an external end face between said first and second leads.

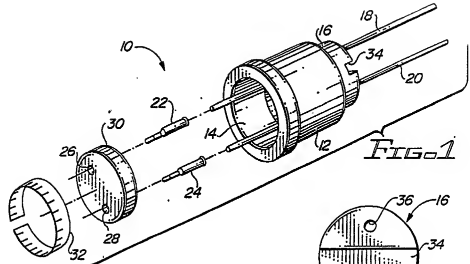


FIG. 1

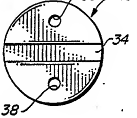


FIG. 2A

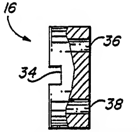


FIG. 2B

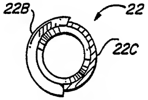


FIG. 3A

FIG. 3B

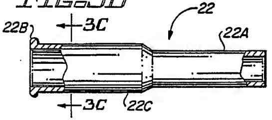
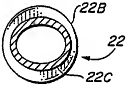


FIG. 3C



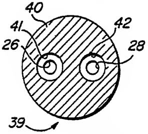


FIG. 4A

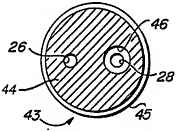


FIG. 4B

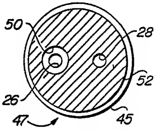


FIG. 4C

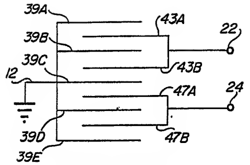


FIG. 5A

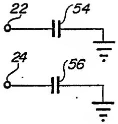


FIG. 5B

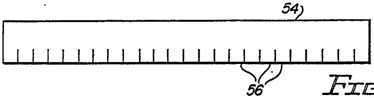


FIG. 6A

FIG. 6B

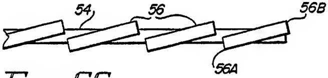


FIG. 6C

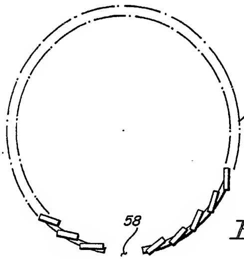


FIG. 6D